International Journal of Thermophysics, Vol. 26, No. 5, September 2005 (© 2005)
DOI: 10.1007/s10765-005-8103-8

Solute–Solvent and Solute–Solute Interactions of Resorcinol in Mixed 1,4-Dioxane–Water Systems at Different Temperatures

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Received October 7, 2004

The densities, viscosities, and ultrasonic speeds of resorcinol in 1,4-dioxane + water mixtures and in pure 1,4-dioxane have been measured at 303.15, 313.15, and 323.15 K. Apparent molar volumes (V_ϕ) and viscosity B-coefficients are obtained from these data supplemented with densities and viscosities, respectively. The limiting apparent molar volumes (V_ϕ^0) and experimental slopes (S_v^*) derived from the Masson equation have been interpreted in terms of solute–solvent and solute–solute interactions, respectively. The viscosity data have been analyzed using the Jones–Dole equation, and the derived parameters B and A have also been interpreted in terms of solute–solvent and solute–solute interactions, respectively. The structure making/breaking capacities of resorcinol in the studied solvent systems have been discussed. The compressibilities obtained from the data supplemented with their ultrasonic speeds indicate the electrostriction of the solvent molecules around the ions.

KEY WORDS: density; electrostriction; mixed aqueous mixtures; resorcinol; solute-solvent and solute–solute interactions; structure maker and breaker; ultrasonic speed; viscosity.

1. INTRODUCTION

Studies on densities, viscosities, and ultrasonic speeds of electrolyte solutions are of great use in characterizing the structure and properties of solutions. Various types of interactions exist between the solutes in solutions, and these solute–solute and solute–solvent interactions are of current interest in all

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branches of chemistry. These interactions provide a better understanding of the nature of the solute and solvent, i.e., whether the solute modifies or distorts the structure of the solvent.

1,4-dioxane and its aqueous mixtures are very important solvents that are widely used in various industries. They figure prominently in the high-energy battery technology and have also found application in organic synthesis as manifested from the physicochemical studies in these media [1–8]. In the present work, an attempt has been made to provide an interpretation of solute–solvent and solute–solute interactions prevailing in the studied electrolyte solutions. Several workers have reported volumetric, viscometric, and ultrasonic studies of this compound in aqueous solutions [9–13], but such studies in pure 1,4-dioxane and its aqueous mixtures are still scarce.

2. EXPERIMENTAL

1,4-dioxane (Merck, India) was kept several days over potassium hydroxide (KOH), refluxed for 24 h, and distilled over lithium aluminium hydride ($LiAlH_4$) as described earlier [1]. Resorcinol (A.R.) was purified by a reported procedure [14], and the compound was dried and stored in a vacuum desiccator. Freshly distilled conductivity water was used.

The densities (ρ) were measured with an Ostwald–Sprengel type pycnometer having a bulb volume of 25 cm^3 and an internal diameter of the capillary of about 0.1 cm. The pycnometer was calibrated at 303, 313, and 323 K with doubly distilled water and benzene. The pycnometer with the test solution was equilibrated in a water bath maintained at ±0.01 K of the desired temperature by means of a mercury-in-glass thermoregulator, and the absolute temperature was determined by a calibrated platinum resistant thermometer and Muller bridge. The pycnometer was then removed from the thermostatic bath, properly dried, and weighed. The evaporation losses remained insignificant during the time of actual measurements. An average of triplicate measurements was taken into account. The total uncertainty of density is $\pm 1.0 \times 10^{-5}\ g \cdot cm^{-3}$ and of the temperature is 0.01 K. Details have been described earlier [5, 15, 16].

The viscosities were measured by means of a suspended-level Ubbelohde [17] viscometer at the desired temperature (uncertainty of ±0.01 K). The precision of the viscosity measurement was $\pm 0.003\ mPa \cdot s$. Details have been described earlier [5,15,16].

Sound speeds were determined with an uncertainty of 0.3 % using a single-crystal variable-path ultrasonic interferometer (Mittal Enterprises, New Delhi, India) operating at 4 MHz which was calibrated with water, methanol, and benzene at each temperature, as described in detail elsewhere [18, 19]. The experimental values of densities (ρ_0) and viscosities

(η_0) of pure 1,4-dioxane and 1,4-dioxane + water mixtures at 303, 313, and 323 K are reported in Table I. The various salt solutions studied here were prepared by mass, and the conversion of molality to molarity was accomplished [20] using density values.

The experimental values of concentrations (c), densities (ρ), viscosities (η), and derived parameters at various temperatures are reported in Table II.

3. DISCUSSION

The apparent molar volumes (V_ϕ) were determined from the solution densities using the following equation:

$$V_\phi = M/\rho_0 - 1000(\rho - \rho_0)/(c\rho_0) \tag{1}$$

where M is the molar mass of the solute, c is the molarity of the solution, and ρ_0 and ρ are the densities of the solvent/solvent mixtures and solution, respectively.

The limiting apparent molar volumes (V_ϕ^0) were calculated using a least-squares treatment to the plots of V_ϕ versus $c^{1/2}$ using the following Masson equation [21]:

$$V_\phi = V_\phi^0 + S_v^* \sqrt{c} \tag{2}$$

where V_ϕ^0 is the partial molar volume at infinite dilution and S_v^* is the experimental slope. The plots of V_ϕ against the square root of the molar concentration ($c^{1/2}$) were found to be linear with negative slopes. The values of V_ϕ^0 and S_v^* along with the standard errors are reported in Table III.

As the investigated systems are characterized by hydrogen bonds, the solute–solvent and solute–solute interactions can be interpreted in terms of structural changes, which arise due to hydrogen bond interactions present between various components of the solvent and solution systems.

To examine the solute–solvent interactions, V_ϕ^0 can be used. Table III shows that the V_ϕ^0 values are positive and increase with a rise in temperature and decrease with an increase in the amount of 1,4-dioxane in the mixtures. This indicates the presence of strong solute–solvent interactions, and these interactions are strengthened with a rise in temperature and weakened with an increase in the amount of 1,4-dioxane in the mixed solvent under investigation, suggesting larger electrostriction at higher temperature and lower amount of 1,4-dioxane in the mixture. Similar results were obtained for some 1:1 electrolytes in aqueous DMF [22] and aqueous THF [1].

Table I. Physical Properties of Pure 1,4-Dioxane and 1,4-Dioxane + Water Mixtures at Different Temperatures

Composition of 1,4-dioxane (mass%)	ρ_0 (g · cm^{-3})						η_0 (mPa · s)					
	303.15 K		313.15 K		323.15 K		303.15 K		313.15 K		323.15 K	
	Exp	Lit	Exp	Lit	Exp	Lit	Exp	Lit	Exp	Lit	Exp	Lit
10	1.0058	–	1.0068	–	0.9973	–	1.0321	–	1.0014	–	0.6895	–
20	1.0148	–	1.0100	–	1.0033	–	1.2014	–	1.0186	–	0.8787	–
30	1.0202	–	1.0162	–	1.0103	–	1.3977	–	1.2493	–	1.0755	–
100 (Pure)	1.0199	1.0222 [20]	1.0144	1.0143 [21]	1.0027	1.0032 [21]	1.0886	1.0937 [20]	0.9785	0.9783 [21]	0.8441	0.8443 [21]

Table II. Concentration (c), Density (ρ), Viscosity (η), Apparent Molar Volume (V_ϕ), and $(\eta/\eta_0 - 1)/\sqrt{c}$ of Resorcinol in Pure 1,4-Dioxane and 1,4-Dioxane + Water Mixtures at Different Temperatures

c (mol·dm^{-3})	ρ (g·cm^{-3})	η (mPa·s)	V_ϕ (cm^3·mol^{-1})	$(\eta/\eta_0 - 1)/\sqrt{c}$
10 mass% of 1,4-dioxane + water				
$T = 303.15$ K				
0.0070	1.0077	1.0376	115.9842	−0.1443
0.0487	1.0076	1.0255	112.5836	−0.1066
0.0905	1.0082	1.0358	103.8412	−0.0456
0.1322	1.0091	1.0507	98.9411	0.0012
0.1740	1.0104	1.0789	94.2994	0.0654
0.2157	1.0119	1.1090	90.3421	0.1205
$T = 313.15$ K				
0.0070	1.0012	0.9408	123.5465	−1.0002
0.0485	1.0009	0.8334	118.5112	−0.8534
0.0901	1.0010	0.8246	112.7892	−0.6544
0.1317	1.0019	0.8351	106.0231	−0.5134
0.1733	1.0030	0.8620	100.3112	−0.3845
0.2150	1.0050	0.9291	92.9054	−0.2042
$T = 323.15$ K				
0.0069	0.9975	0.6834	130.0254	−0.7280
0.0482	0.9971	0.6939	122.5432	−0.2092
0.0895	0.9972	0.7609	115.1204	0.1544
0.1307	0.9979	0.8931	108.6753	0.6304
0.1724	0.9991	1.0793	101.8734	1.1654
0.2140	1.0009	1.2354	94.8752	1.5102
20 mass% of 1,4-dioxane + Water				
$T = 303.15$ K				
0.0071	1.0164	1.2205	114.9854	−0.0543
0.0498	1.0163	1.2180	110.8887	−0.0296
0.0925	1.0165	1.2265	107.7832	0.0012
0.1352	1.0172	1.2391	102.8712	0.0290
0.1779	1.0187	1.2563	95.8097	0.0584
0.2206	1.0207	1.2699	89.0009	0.0761
$T = 313.15$ K				
0.0071	1.0099	0.9489	118.0543	0.0011
0.0495	1.0098	0.9681	112.9843	0.0914
0.0919	1.0100	0.9939	108.5632	0.1569
0.1343	1.0106	1.0231	104.2871	0.2135
0.1768	1.0118	1.0648	98.7358	0.2906
0.2197	1.0142	1.1113	90.3320	0.3654

Table II. *(Continued)*

c (mol · dm^{-3})	ρ (g · cm^{-3})	η (mPa · s)	V_ϕ (cm^3 · mol^{-1})	$(\eta/\eta_0 - 1)/\sqrt{c}$
$T = 323.15$ K				
0.0070	1.0035	0.8595	121.0065	−0.5165
0.0493	1.0034	0.8189	113.8901	−0.3984
0.0912	1.0036	0.8198	109.9987	−0.2897
0.1340	1.0041	0.8554	106.0007	−0.1305
0.1759	1.0054	0.9046	99.5709	0.0165
0.2179	1.0075	0.9486	91.9964	0.1198
30 mass % of 1,4-dioxane + Water				
$T = 303.15$ K				
0.0070	1.0202	1.4376	103.6557	0.1006
0.0491	1.0208	1.4635	95.5644	0.1200
0.9125	1.0218	1.4805	90.5848	0.1277
0.1334	1.0229	1.4972	87.6753	0.1376
0.1755	1.0241	1.5177	85.6229	0.1544
0.2176	1.0267	1.5326	78.6543	0.1609
$T = 313.15$ K				
0.0070	1.0163	1.2855	105.0988	0.1015
0.0489	1.0168	1.3091	97.6876	0.1223
0.0910	1.0177	1.3260	92.8904	0.1334
0.1328	1.0189	1.3402	88.9876	0.1410
0.1748	1.0202	1.3602	85.9498	0.1605
0.2167	1.0226	1.3787	79.6544	0.1754
$T = 323.15$ K				
0.0070	1.0106	1.1076	106.5169	0.1017
0.0486	1.0111	1.1279	99.6003	0.1222
0.0902	1.01189	1.1445	95.0065	0.1401
0.1318	1.01318	1.1607	89.6543	0.1565
0.1736	1.0143	1.1763	87.8954	0.1704
0.2149	1.0167	1.1899	80.9976	0.1799
Pure 1,4-dioxane				
$T = 303.15$ K				
0.0069	1.0203	1.1108	47.4532	0.2540
0.0485	1.0226	1.1514	53.0001	0.2655
0.0902	1.0245	1.1782	57.5543	0.2765
0.1319	1.0261	1.2001	61.8776	0.2841
0.1736	1.0278	1.2222	62.9876	0.2965
0.2152	1.0292	1.2461	65.4432	0.3137

Table II. *(Continued)*

c ($\text{mol}\cdot\text{dm}^{-3}$)	ρ ($\text{g}\cdot\text{cm}^{-3}$)	η ($\text{mPa}\cdot\text{s}$)	V_ϕ ($\text{cm}^3\cdot\text{mol}^{-1}$)	$(\eta/\eta_0-1)/\sqrt{c}$
$T=313.15\,\text{K}$				
0.0069	1.0147	0.9990	49.4987	0.2544
0.0480	1.0169	1.0362	54.7654	0.2701
0.0894	1.0186	1.0592	60.4765	0.2765
0.1308	1.0202	1.0809	63.8765	0.2901
0.1721	1.0219	1.1041	64.9998	0.3100
0.2134	1.0233	1.1224	66.6279	0.3190
$T=323.15\,\text{K}$				
0.0068	1.0036	0.8621	50.6542	0.2551
0.0475	1.0058	0.8942	55.9786	0.2709
0.0884	1.0075	0.9146	61.8881	0.2801
0.1293	1.0091	0.9347	64.7831	0.2976
0.1702	1.0107	0.9551	65.8160	0.3176
0.2110	1.0122	0.9738	67.5301	0.3339

It is evident from Table III that the S_V^* values are negative for all temperatures for aqueous mixtures of 1,4-dioxane, but positive for pure 1,4-dioxane. Since S_V^* is a measure of solute–solute interactions, the results indicate the presence of weak solute–solute interactions. These interactions, however, decrease with a rise in temperature, which is attributed to more violent thermal agitation at higher temperatures, resulting in diminishing the force of solute–solute interactions (ionic dissociation) [7]. The S_V^* values increase with an increase in the amount of 1,4-dioxane in the mixture which results in a decrease in solvation of ions, i.e., more and more solute is accommodated in the void space left in the packing of large associated solvent molecules with the addition of 1,4-dioxane to the mixture.

The variation of V_ϕ^0 with temperature of resorcinol in solvent mixtures follows the polynomial,

$$V_\phi^0 = a_0 + a_1T + a_2T^2 \tag{3}$$

over the temperature range under investigation where T is the temperature in K.

Values of coefficients of the above equation for resorcinol for compositions of 1,4-dioxane + water mixtures are reported in Table IV.

From the values of coefficients the following equations are obtained: 10 mass% 1,4-dioxane + water mixture

Table III. Limiting Apparent Molar Volume (V_ϕ^0) and Experimental Slope (S_v^*) for Resorcinol in Different 1,4-Dioxane + Water Mixtures at Different Temperatures

	V_ϕ^0 (cm$^3 \cdot$ mol^{-1})			S_v^* (cm$^2 \cdot$ dm$^{1/2} \cdot$ mol$^{-3/2}$)		
Composition of 1,4-dioxane (mass%)	303.15 K	313.15 K	323.15 K	303.15 K	313.15 K	323.15 K
10	124.5 (±0.05)	133.5 (±0.02)	140.5 (±0.04)	−70.8 (±0.02)	−79.6 (±0.01)	−92.2 (±0.04)
20	123.8 (±0.01)	126.6 (±0.03)	129.1 (±0.02)	−64.8 (±0.04)	−67.8 (±0.03)	−71.2 (±0.02)
30	109.1 (±0.01)	111.3 (±0.05)	113.0 (±0.02)	−60.6 (±0.03)	−63.4 (±0.01)	−64.1 (±0.02)
100	43.1 (±0.01)	45.5 (±0.02)	46.8 (±0.01)	48.5 (±0.02)	47.5 (±0.04)	46.7 (±0.01)

Standard errors are given in parentheses.

$$V_{\phi}^{0} = -\,1123.39/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1} + 7.23T/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1}\cdot\mathrm{K}^{-1} - 0.010T^{2}/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1}\cdot\mathrm{K}^{-2} \tag{4}$$

20 mass % 1,4-dioxane + water mixture

$$V_{\phi}^{0} = -\,74.86/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1} + 1.02T/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1}\cdot\mathrm{K}^{-1} - 0.001T^{2}/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1}\cdot\mathrm{K}^{-2} \tag{5}$$

30 mass % 1,4-dioxane + water mixture

$$V_{\phi}^{0} = -\,216.27/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1} + 1.89T/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1}\cdot\mathrm{K}^{-1} - 0.002T^{2}/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1}\cdot\mathrm{K}^{-2} \tag{6}$$

Pure 1,4-dioxane

$$V_{\phi}^{0} = -\,500.30/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1} + 3.30T/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1}\cdot\mathrm{K}^{-1} - 0.005T^{2}/\mathrm{cm}^{3}\cdot\mathrm{mol}^{-1}\cdot\mathrm{K}^{-2} \tag{7}$$

The apparent molar expansibilities (Φ_{E}^{0}) can be obtained by the following equation:

$$\Phi_{\mathrm{E}}^{0} = (\delta V_{\phi}^{0}/\delta T)_{\mathrm{P}} = a_0 + 2a_2T \tag{8}$$

The values of Φ_{E}^{0} of the studied compounds at 303.15, 313.15, and 323.15 K are determined and reported in Table V.

Table IV. Values of Various Coefficients for Resorcinol in Different 1,4-Dioxane + Water Mixtures

Composition of 1,4-dioxane (mass %)	a_0 ($\mathrm{cm}^3\cdot\mathrm{mol}^{-1}$)	a_1 ($\mathrm{cm}^3\cdot\mathrm{mol}^{-1}\cdot\mathrm{K}^{-1}$)	a_2 ($\mathrm{cm}^3\cdot\mathrm{mol}^{-1}\cdot\mathrm{K}^{-2}$)
10	−1123.39	7.23	−0.010
20	−74.86	1.02	−0.001
30	−216.27	1.89	−0.002
100	−500.30	3.30	−0.005

It is found from Table V that the values of Φ_{E}^{0} decrease with a rise in temperature as well as with an increase in the amount of 1,4-dioxane in the mixture, which can be ascribed to the absence of caging or packing effects [23].

During the past few years it has been emphasized by different workers that S_{V}^{*} is not the sole criterion for determining the structure-making or breaking nature of any solute. Hepler [24] developed a technique of examining the sign of $(\delta^2 V_{\phi}^{0}/\delta T^2)_{\mathrm{P}}$ for the solute in terms of long-range structure-making and breaking capacity of the solute in the mixed solvent systems using the general thermodynamic expression,

$$(\delta c_{\mathrm{P}}/\delta P)_T = -(\delta^2 V_{\phi}^{0}/\delta T^2)_{\mathrm{P}} \tag{9}$$

On the basis of this expression, it has been deduced that the structure-making solutes should have positive values, whereas structure-breaking solutes should have negative values. In our present investigation, it is evident from Table V that $(\delta^2 V_{\phi}^{0}/\delta T^2)_{\mathrm{P}}$ values are negative for resorcinol and for all 1,4-dioxane + water mixtures investigated here, suggesting thereby that resorcinol acts as a structure breaker in these solvent mixtures.

The viscosity data of solutions for resorcinol in 10, 20, and 30 mass% of 1,4-dioxane + water mixtures and pure 1,4-dioxane have been analyzed using the Jones–Dole [25] equation:

$$\begin{aligned} \eta/\eta_0 &= 1 + Ac^{1/2} + Bc \\ (\eta/\eta_0 - 1)/c^{1/2} &= A + Bc^{1/2}, \qquad \text{where } \eta = (kt - L/t)\rho, \end{aligned} \tag{10}$$

and η_0 and η are the viscosities of solvent/solvent mixtures and solution, respectively. k and L are the constants for a particular viscometer, and t is

Table V. Limiting Apparent Molar Expansibilities (Φ_{E}^{0}) for Resorcinol in Various 1, 4-Dioxane + Water Mixtures at Different Temperatures

	Φ_{E}^{0} $(\mathrm{cm^3 \cdot mol^{-1} \cdot K^{-1}})$			
Composition of 1,4-dioxane (mass%)	303.15 K	313.15 K	323.15 K	$(\delta \Phi_{\mathrm{E}}^{0}/\delta T)_P$
10	1.01	0.81	0.59	Negative
20	0.29	0.27	0.24	Negative
30	0.25	0.19	0.14	Negative
100 (Pure)	0.29	0.19	0.09	Negative

the flow time of the solvent/solution in seconds. A and B are the constants which are estimated by a least-squares method and reported in Table VI.

A perusal of Table VI shows that the values of the A coefficient are negative for 10 and 20 mass% of 1,4-dioxane and positive for 30 and 100 mass% of 1,4-dioxane for all temperatures. These results indicate the presence of weak solute–solute interactions, and these interactions increase with an increase of 1,4-dioxane to the mixture.

It is also observed from Table VI that the values of the B-coefficient of resorcinol in the studied solvent systems are positive, thereby suggesting the presence of strong solute–solvent interactions, and these types of interactions are strengthened with a rise in temperature and weakened with an increase of 1,4-dioxane in the mixture. These conclusions are in excellent agreement with those drawn from V_{ϕ}^{0} values discussed earlier.

It has been reported in a number of studies [26, 27] that dB/dT is a better criterion for determining the structure-making/breaking nature of any solute rather than simply the value of the B-coefficient. It is found from Table VI that the values of the B-coefficient increase with a rise in temperature (positive dB/dT) suggesting the structure-breaking tendency of resorcinol in the solvent systems. A similar result was reported in a study [30] for the case of the viscosity of some salts in propionic acid + ethanol mixtures.

The adiabatic compressibility (β) was calculated from the following relation:

$$\beta = 1/(u^2 \rho) \tag{11}$$

where ρ is the solution density and u is the sound speed in the solution. The apparent molal adiabatic compressibility (Φ_K) of the liquid solutions was determined from the relation,

$$\Phi_{\mathrm{K}} = M\beta/\rho_0 + 1000(\beta\rho_0 - \beta_0\rho)/(m\rho\rho_0) \tag{12}$$

The limiting apparent molal adiabatic compressibility (Φ_{K}^{0}) was obtained by extrapolating the plots of Φ_{K} versus the square root of molal concentration of the solute to zero concentration by a least-squares method.

$$\Phi_{\mathrm{K}} = \Phi_{\mathrm{K}}^{0} + S_{\mathrm{K}}^{*} m^{1/2} \tag{13}$$

where S_{K}^{*} is the experimental slope.

Table VI. Values of A and B Parameters for Resorcinol in Different 1,4-dioxane + Water Mixtures at Different Temperatures

	A ($cm^{3/2} \cdot mol^{-1/2}$)			B ($cm^3 \cdot mol^{-1}$)		
Composition of 1,4-dioxane (mass%)	303.15 K	313.15 K	323.15 K	303.15 K	313.15 K	323.15 K
10	−0.23 (±0.01)	−1.24 (±0.02)	−1.41 (±0.01)	0.70 (±0.01)	2.08 (±0.02)	5.95 (±0.02)
20	−0.09 (±0.01)	−0.10 (±0.02)	−0.73 (±0.02)	0.35 (±0.01)	0.92 (±0.02)	1.70 (±0.01)
30	0.08 (±0.01)	0.08 (±0.01)	0.07 (±0.02)	0.16 (±0.01)	0.18 (±0.02)	0.21 (±0.02)
100	0.24 (±0.02)	0.23 (±0.01)	0.23 (±0.01)	0.15 (±0.02)	0.17 (±0.02)	0.21 (±0.01)

Standard errors are given in parentheses.

Table VII. Molality (m), Density (ρ), Sound Speed (u), Adiabatic Compressibility (β), Apparent Molal Adiabatic Compressibility (Φ_K), Limiting Apparent Adiabatic Compressibility (Φ_K^0), and Experimental Slope (S_K^*) of Resorcinol in Different 1,4-Dioxane + Water Mixtures at 303.15 K

Composition of 1,4-dioxane (mass%)	m ($\mathrm{mol \cdot kg^{-1}}$)	$\rho \times 10^{-3}$ ($\mathrm{kg \cdot m^{-3}}$)	u ($\mathrm{m \cdot s^{-1}}$)	$\beta \times 10^{10}$ ($\mathrm{Pa^{-1}}$)	$\Phi_K \times 10^{10}$ ($\mathrm{m^3 \cdot mol^{-1} \cdot Pa^{-1}}$)	$\Phi_K^0 \times 10^{10}$ ($\mathrm{m^3 \cdot mol^{-1} \cdot Pa^{-1}}$)	$S_K^* \times 10^{10}$ ($\mathrm{m^3 \cdot mol^{-3/2} \cdot Pa^{-1} \cdot kg^{1/2}}$)
10	0.00691	1.00769	1576.73	3.99168	1.050		
	0.04861	1.00758	1572.70	4.01262	0.963		
	0.09064	1.00824	1570.36	4.02194	0.794	1.31 (±0.02)	−2.02(±0.04)
	0.13296	1.00912	1573.30	4.00343	0.515		
	0.17555	1.01037	1573.09	3.99957	0.446		
	0.21835	1.01186	1575.75	3.98003	0.327		
20	0.00701	1.01637	1590.39	3.88993	1.440		
	0.04928	1.01629	1584.30	3.92019	1.180		
	0.09193	1.01647	1586.07	3.91075	0.720		
	0.13488	1.01717	1590.98	3.88397	0.408	1.81 (±0.03)	−3.58(±0.05)
	0.17805	1.01868	1593.76	3.86472	0.271		
	0.22137	1.02075	1596.57	3.84330	0.168		
30	0.00687	1.02019	1590.07	3.87045	2.850	3.47 (±0.02)	−7.63(±0.03)
	0.04839	1.02078	1580.33	3.92260	1.910		
	0.09019	1.02178	1583.03	3.90540	0.991		
	0.13227	1.02291	1584.14	3.89559	0.704		
	0.17463	1.02415	1595.59	3.83525	0.265		
	0.21699	1.02666	1605.11	3.78063	0.001		

Standard errors are given in parentheses.

The values of $u, \beta, \Phi_K, \Phi_K^0$, and S_K^* are reported in Table VII.

A perusal of Table VII shows that the Φ_K^0 values increase whereas S_K^* values decrease with an increase of 1,4-dioxane in the mixtures for the compounds studied here. Since the values of Φ_K^0 and S_K^* are measures of the solute–solvent and solute–solute interactions, respectively, the results are in good agreement with those drawn from the conclusion based on the values of Φ_K^0 and S_K^* explained here earlier. The same result was obtained by us [29] in studies on the sound speeds of some salts in different tetrahydrofuran (THF) + water mixtures.

ACKNOWLEDGMENT

The authors are grateful to the Departmental Special Assistance Scheme under the University Grants Commission, New Delhi (No. 540/6/DRS/2002, SAP-1) for financial support.

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